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THE LEVELS OF THE LAKES

AS AFFECTED BY THE PROPOSED

LAKES AND GULF WATERWAY.

A DISCUSSION

BEFORE

THE WESTERN SOCIETY OF ENGINEERS,

BY

George Y. Wisner, L. E. Cooley, L. M. Haupt, Clemens Herschel, William
Pierson Judson, J. B Johnson, Walter P. Rice, D.
Farrand Henry, and Benezette Williams.

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ADDENDA.

PERSONAL NOTES.

The following personal memoranda are inserted by the Citizens' Association and are designed to show the weight to be attached to the writings of the inclosed pages and to the opinions of those mentioned therein:

GEO. Y. WISNER, Resident Engineer Jetties at mouth of Mississippi, Port Eads, La.—Mr. Wisner has been upon lake, river and harbor work for over twenty years. For many years he was connected with the surveys of the Great Lakes and afterwards with those upon the Mississippi under the Mississippi River Commission. He was in immediate charge of the examinations for the enlargement of the Illinois and Michigan Canal as an extension of the proposed Hennepin Canal to Chicago and of the surveys of the Illinois River from La Salle to Joliet, with a view to the extension of the river improvement below La Salle toward Chicago. These surveys form the basis of all studies for this portion of the river. More recently, he has been upon harbor and lighthouse duty about the lakes. It will be seen that Mr. Wisner is familiar with all parts of the system to be affected by the proposed waterway.

L. E. COOLEY, Consulting Engineer, Drainage Project, Chicago.—Mr. Cooley has been engaged in matters pertaining to hydraulic engineering and to waterways for fourteen years, and was for several years in responsible positions upon physical investigations, surveys and construction on the Missouri and Mississippi rivers. As a member of the Drainage Committee of Citizens' Association in 1885, he proposed substantially the project since investigated and recommended for the drainage of Chicago. He was Principal Assistant Engineer upon the Drainage Commission, and has at all times steadily promoted the waterway view of the problem and written much in regard thereto.

LEWIS M. HAUPT, Professor of Engineering, University of Pennsylvania, Philadelphia, Pa.—Prof. Haupt is a son of Gen. Haupt, well-known in engineering and railway circles and as an author on technical subjects. He is a graduate of West Point, and has seen service as an officer of engineers upon harbor work. He is well known as a writer upon waterway economics. Recently he has made an elaborate and original study of improvement of tidal harbors, and received therefor the Magellan Medal from the American Philosophical Society, a prize given but six times in a century.

CLEMENS HERSCHEL, Engineer Water Power Co., Holyoke, Mass.—Mr. Herschel has a national reputation as a hydraulic engineer, and especially in regard to river hydraulics and the measurement of the flow of streams. He is a writer on waterway economics. His practice has been largely in New England.

J. B. JOHNSON, Professor of Engineering, Washington University, St. Louis, Mo.—Professor Johnson was for several years engaged in the surveys upon the lakes and upon the Mississippi River, and especially in precise level work for determining elevations of the lakes and in investigating physical phenomena. He is known as a writer upon these subjects.

WM. PIERSON JUDSON, Civil Engineer in service of the United States upon harbor work about Lake Ontario, and upon fortifications about the Great Lakes, Oswego, N. Y.—Mr. Judson has been for many years familiar with the lakes and has lately interested himself as a promoter of a ship canal for vessels of twenty feet draft from Lake Erie to Lake Ontario, around Niagara Falls upon the American side. The Chicago Board of Trade has interested itself in this enterprise.

WALTER P. RICE, City Civil Engineer, Cleveland, Ohio.—Mr. Rice was for several years a civil engineer in the service of the United States upon the improvements of Lake Erie and upon other work. He has made several physical investigations in regard to the phenomena of this lake and of Lake Ontario.

D. FARRAND HENRY, Civil Engineer, Detroit, Mich.—Mr. Henry was engaged upon the Lake Survey for several years previous to 1870, and was especially charged with the meteorological work and the measurement of the outflow of the several lakes. Mr. Henry's hydraulic investigations have received wide attention from students of river physics. Mr. Henry has since engaged in practice as a hydraulic engineer.

BENEZETTE WILLIAMS, Civil and Sanitary Engineer, Chicago, Ill.—During the time of Mr. E. S. Chesbrough, Mr. Williams was connected with the Engineer Department of the city of Chicago for seven years. For a portion of the time he was in charge of the Sewer Department and afterward occupied the position of City Engineer. During the past nine years he has been engaged in sewerage and water-works practice, his most notable work being the sewerage of Pullman, Ill., practically the first and still the best example of land disposal in this country. Mr. Williams was a member of the Drainage Commission which recommended the Desplaines Valley Ship Canal for the disposal of the sewage of Chicago, the project now under discussion.

ROBERT E. McMATH, Sewer Commissioner, St. Louis, Mo.—Mr. McMath was for twenty years identified with Western river improvements. Under General Wilson he made surveys and studies of the Illinois River, and was in charge of its improvement. At that time he protested against an improvement by locks and dams. Later, he was engaged upon the improvement of the Mississippi from St. Louis to Cairo, and afterward upon physical studies for the Mississippi River Commission. Mr. McMath is well known in the literature pertaining to the hydraulics of our great rivers. Mr. McMath's paper upon "The Waterway Between Lake Michigan and the Mississippi River by Way of the Illinois River," has been republished by the Citizens Association.

JAMES H. WILSON, Wilmington, Del.—General Wilson, after the Civil War, was in charge of the Upper Mississippi and the Illinois Rivers, and inaugurated the improvements at the rapids at Rock Island and at Des Moines. He made a comprehensive investigation of the Illinois River, and recommended (1868) the project since known as the Wilson project, in conformity to which all improvements of the Illinois have been made. Since leaving the army, General Wilson has been engaged upon railway enterprises at home and abroad. He now states that the ship canal project is more fully justified than his project was twenty years ago. General Wilson's letter is appended to the "Brief upon the Lakes and Gulf Waterway," published by the Citizens' Association.

Reprinted from the Journal of the Association of Engineering Societies, March, 1889.

Levels of the Lakes as Affected by the Proposed Lake Michigan and Mississippi Waterway.

By Geo. Y. Wisner and Others.*

[Read before the Western Society of Engineers, Sept. 5, 1888, and at subsequent meetings.]

Introductory: The Proposed Waterway.
Levels of the Lakes, etc., by Geo. Y. Wisner.
Discussion, by L. E. Cooley, L. M. Haupt, Clemens Herschel, J. B. Johnson, Wm. Pierson Judson, Walter P. Rice, D. Farrand Henry, Benezette Williams
Data pertaining to the outflow of the lakes.

Prefatory.

An effect upon the level of the lakes, injurious to navigation, by the turning of a large volume of water across the Chicago divide, has been intimated from quarters not in sympathy with the project for a great drainage and navigation channel from Lake Michigan at Chicago via the Desplaines and Illinois River to the Mississippi, and ultimately to the Gulf of Mexico. These suggestions do not profess to be based upon any technical consideration of the data, but have, nevertheless, been seized upon with avidity by those opposed, for various reasons, to the realization of any such project, and many doubts have thus been raised throughout the Lake region and in the Mississippi Valley, and have even found expression upon the floor of the U. S. Senate.

It has seemed very proper, therefore, that the Western Society of Engineers, as representing the profession most fully in the region in question, should give a preliminary consideration to the matter from the existing data. Accordingly, Mr. Wisner's paper has been laid before the Society and discussion invited from others of long experience upon the lakes or the rivers to be affected by the proposed contribution of water, or those expert in kindred hydraulic problems. The oral discussions have been of much interest, but have not been reported. The several papers submitted, together with matter germane to the question, are herewith compiled and publication authorized by order of the Society.

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*Compiled and edited by L. E. Cooley, Member of Western Society of Engineers.

Introductory: The Proposed Waterway.

For those unfamiliar with the general project, a résumé of the essential features is thought advisable. For a more comprehensive presentation of the scheme, the reader is referred to a brief upon "The Lakes and Gulf Waterway," published by the Citizens' Association of Chicago, January, 1888; and also to "The Waterway between Lake Michigan and the Mississippi River, by way of the Illinois River," by Robt. E. McMath, Member of the Engineers' Club of St. Louis, published in the JOURNAL for August, 1888.*

In comparatively recent geological time, the three upper lakes—Superior, Huron and Michigan—discharged their waters across the Chicago divide and down the Illinois and Mississippi to the Gulf. Lake Erie was then a valley tributary to Lake Ontario, which, with Lake Champlain, fed the St. Lawrence. Across the old divide from lake level to lake level is but 30 miles, about one-half the distance being rock. This rock lies but 8 feet above low water in the lake and but 4 feet above high water, and alluvial deposits to a height of 12 feet above low water are of limited extent. The obstacle is far less than that overcome nearly seventy years ago in carrying the level of Lake Erie by the Erie Canal from Buffalo and the Tonawanda River across the mountain ridge to Lockport.

Around Chicago beach lines are well developed at about the right elevation to give to the old outlet the discharging capacity of the present Niagara. At 40 miles from the lake the valley is 77 feet below the lake, and in 100 miles the head of the alluvial valley is reached in a descent of 142 feet. The alluvial valley, with a wide and low flood plane, much cut up by swamp and lake, extends for 225 miles to the Mississippi, with a grade of only 26 feet. The evidence everywhere is significant of the ancient outlet, and it is marvelous that the erosive forces should have failed by so narrow a margin to maintain it, and in the epoch since to have completed the grade to Lake Michigan. Then would Michigan and Huron have been a hundred feet lower without material impairment of area, and the outflow would have given a continuous depth of not less than 30 feet to the Gulf of Mexico. How far can man realize the primitive conditions?

The arable area of North America is largely embraced in two continental valleys or basins, or virtually one trough, extending from the Gulf of Mexico by the lakes to the Gulf of St. Lawrence. The lowest line of this trough, its thalweg, is necessarily the feasible route for a continental waterway, and the summit is the Chicago divide, 200 feet lower than any other pass from the basin of the lakes to that of the Mississippi. Eastward, the descent is almost entirely in rockbound channels and by precipitous falls and rapids. Southward, it is on a grade through alluvial plains. The improvement eastward demands but a small volume of water, the levels maintained by dams and the descents overcome by short canals and locks; the improvement southward demands a large flow at seasons of low water to maintain a proper channel for navigation through the mobile alluvium. These considerations make evident the treatment required for the greatest waterway, and we can believe that the largest useful depth is feasible and within the resources and wisdom of the nation. If so grand a purpose is within engineering resource, all the relations of a project which only approaches it in a minor and fractional degree can certainly be met, and it may well be so designed that in a progressive development from present needs the greater purpose can in some future be realized.

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* For copies of these papers address the Citizens' Association, Chicago.

The Illinois & Michigan Canal, from Chicago to La Salle, 100 miles, was completed in 1848, and in 1871 the summit level was cut down so as to carry from 200 to 550 cubic feet per second by gravity, according to the stage of water in Lake Michigan. This reversed the current in the Chicago River, and conducted to the valley, 30 miles from Chicago, the major portion of the sewage of the city so far as it was undecomposed by the time the canal was reached. The nuisance in the valley was so great that in 1882 the city was compelled to erect pumps of 1,000 cubic feet capacity per second, and these have been operated to about 800 cubic feet during the past two years. The maximum capacity of the canal by pumping is about 1,500 cubic feet.

At the present writing the sewage of about 800,000 population and a host of waste-producing industries is nominally tributary to the canal, but no inconsiderable proportion is quite decomposed before the canal is reached, and all is more or less "oxidized," so that the condition of the canal by no means represents the pollution which would be occasioned by fresh sewage. The present contribution to the Illinois Valley is the cause of loud protests.

That some radical solution of the situation would be required has been recognized in some degree for ten years. In 1885 a committee of the Citizens' Association carefully reviewed all the feasible plans, and concluded that a ship canal carrying a large volume of water to the Illinois was altogether the least expensive, and at the same time covered the costly section of a deep waterway to the Mississippi. The volume, so far as then discussed, was assumed at 10,000 cubic feet per second.

During the following year, a drainage commission was organized and expended $65,000, but did not complete its work and make a final report. Its preliminary report of January, 1887, rejected all other solutions on account of cost, and recommended the ship channel with a minimum capacity of 10,000 cubic feet. As a channel of this capacity and not less than 160 feet wide and 22 feet deep, it was favorably reported by a joint committee of the General Assembly of Illinois in the spring of the same year.

The estimate at that time on the dilution required varied from 250 to 350 feet per second for each 100,000 of population. The recommendation was considered sufficient for 2,500,000 population, and was equivalent to 400 feet per second for each 100,000 people. This larger estimate was, however, based on the capacity required to keep the sewage from backing out into the lake when the channel was taxed by storm water from the tributary water-shed.

The observations since made indicate that the larger ratio of dilution may be required for a satisfactory sanitary condition, though the question has not been conclusively determined. Additional light will be thrown upon the matter by the observations now in progress by the

State Board of Health. The probable growth of population is, however, greater than hitherto estimated, and whatever ratio is finally fixed upon, 10,000 cubic feet per second will provide for a brief enough time in the future.

The present population of the metropolitan area, Chicago and immediate suburbs, is 1,025,000, a growth of 450,000 in the last eight years, and the probable population is 1,175,000 in 1890. The normal growth curve indicates a population of 3,000,000 in about twenty years, while the most pessimistic analysis cannot assign over thirty-three years. Considering the political agencies to be provided and the interests of the State and Nation, it will be not less than six to eight years before the work can be completed.

This volume of water will render the improvement of the Illinois a very simple matter, will give 7 feet without locks and dams in the alluvial section, a depth which can be increased to 14 feet by dredging. The government is now engaged in the consideration of a project for this depth of water on the basis of this contribution from Lake Michigan. It will also add not less than 1 foot to the depth for navigation from the mouth of the Illinois to Cairo and 6 inches below Cairo. The present project for the improvement of the Illinois is by locks and dams for a light draft steamboat navigation, and a limited proportion of the work to reach Lake Michigan has been done. The natural conservatism of the official mind is most difficult to change in favor of a bolder and more useful project from an unauthorized source.

The deep channel proposed is economical for carrying a large volume of water and for easy navigation, and will provide much needed harbor facilities for vessels of deep draft. It will also cover one-half the cost of carrying 20 feet of water 300 miles from Chicago, thus, for practical purposes, adding another lake to the great chain and extending a commerce, which has shown phenomenal growth in recent times, while marine interest elsewhere show decadence.

The following series of papers relate to the effect upon the lake level of abstracting 10,000 cubic feet per second through an artificial outlet. Other questions have been raised, as, for instance, the damage to result in the valley from the addition to present normal flow. This is not important, however, as under the most unfavorable assumptions the aggregate cannot exceed a small percentage of the proposed outlay. This matter has been considered and the objection is not now raised except to secure proper legislative provision.

No doubt, legislation expressing the will of the State of Illinois and providing the necessary political machinery to enable Chicago to undertake this work will be had during the session of the General Assembly of 1889.

" LEVELS OF THE LAKES, ETC."

By Geo. Y. Wisner, Member of the American Society of Civil Engineers.

The elevation of the lake surfaces for any given year is a function of the volume of rainfall on the drainage basin, the amount of evaporation and the outflow through the river system.

The rainfall and evaporation for Lakes Michigan and Huron each vary from 20 inches to 30 inches per annum, but are seldom equal for the same year. Years of maximum rainfall are often those of minimum evaporation and vice versa.

For this reason the rainfall and water level curves are seldom symmetrical for any two consecutive years.

The clearing up of the dense forests which formerly surrounded the lakes has undoubtedly had a modifying influence on the fluctuations of the water surfaces. In cases of heavy freshets, the water finds its way into the main streams and thence into the lakes in a few days, where formerly it would have been held for weeks in the immense swamp reservoirs which existed throughout the surrounding forests. The ground being subjected to greater extremes of drought, the average evaporation is less and the volume of water that finds its way to the lakes is consequently greater than formerly.

These fluctuations of the lake surface have only a relative bearing on the question of effect of outflow on the lake levels, and need not be considered in this discussion.

The probable effect of withdrawing from Lake Michigan or from the St. Clair and Detroit rivers 10,000 cubic feet per second (the amount proposed for the discharge through the waterway) is not susceptible of an accurate determination from the data that can now be obtained ; yet it would seem that with the knowledge we have of the physical features of the river system a much closer approximation ought to be arrived at than the various estimates that have been made would indicate. As it may be several years before complete data for a full discussion of the flow of water through the river system is obtained, it is desirable that the change of lake levels, due to the withdrawal of a portion of the discharge to supply artificial outlets, should be determined as closely as possible from the knowledge now at our disposal.

The only determination that has been made of the discharge of the St. Clair River is that made by the U. S. Lake Survey during 1867, 1868 and 1869, which for the mean level of Lake Huron gives a discharge of about 225,000 cubic feet per second.

Mr. Chas. Crosman, in his recent "Chart of the Fluctuation of the Lake Surfaces," gives the mean discharge for the St. Clair River as 225,000 cubic feet per second, which is probably approximately correct.

The difference of the mean levels of the water surfaces of Lake Erie and Lake Huron is 8.4 feet distributed along the river system as follows:

Detroit River, 27 miles	3.0 feet
Lake St. Clair, 16 miles	0.0 feet
St. Clair River, 41 miles	5.4 feet

The greater portion of the fall in the Detroit River is in the lower six miles, in the vicinity of the Lime Kiln crossing. The St. Clair River at the foot of Lake Huron is about one-half mile wide, and in a distance of 2,500 feet down stream narrows up to 750 feet in width, and for the distance of more than a mile flows with a mean velocity of about 7·5 feet per second, or 5 miles per hour. From the foot of these rapids to the head of the delta, 12 miles above Lake St. Clair, the river has a large cross section, and flows with nearly a uniform velocity of 3.0 feet per second, or two miles per hour. From the above it is evident that most of the fall must occur at the rapids and in the delta above Lake St. Clair.

On page 607 of the Final Report of the U. S. Lake Survey, the slope of the river at St. Clair is given as 0.5 inch per mile. This, however, seems somewhat small, for by taking numerous cross-sections of the river between Port Huron and the head of the delta and applying Kutter s formula, a slope of 0.75 inch per mile is found necessary to give a discharge of 225,000 cubic feet per second. Applying the same formula for the cross-section at the rapids, a slope of 10 inches per mile is obtained for the same discharge. The fall at the rapids will be increased by the head required to produce the high velocity. The 5.4 feet fall of the St. Clair River must consequently be distributed somewhat as follows:

Lake Huron to foot of rapids, 1.5 miles, about.......	1.90 feet.
Foot of rapids to head of Delta, 28 miles, 0.75 inches per mile.........	1.75 "
Head of Delta to Lake St. Clair, 11¾ miles, 1.8 inches per mile......	1.75 "

From a consideration of the above physical features of the St. Clair River, it is evident that a change of level of the water surface of Lake Huron would not materially affect the slope of the main river, but would have its principal effect on the slope of the rapids. This is well illustrated by the discharge observations made at St. Clair in 1867. The results for discharge on different dates have ranges of over twenty per cent. of total volume of discharge with scarcely any change of the gauge reading at the place of observation.

This change of velocity of current was undoubtedly due to fluctuation of the water surface of Lake Huron caused by winds and changes of barometric pressure. These fluctuations probably varied from 6 inches to 2 feet in amplitude, and yet the effect on the height of water at St. Clair was hardly noticeable. Taking the mean velocity of the current at the rapids as 7.5 feet per second and the slope at 10 inches per mile for a mean stage of water in Lake Huron, a change of 10,000 cubic feet per second in the volume of discharge would correspond to a change of 2.0 inches in the slope on the rapids, and the change in head due to velocity would be about 0.75 inch. As the water level below would be affected about 0.5 inch, the total effect of change of volume would be equivalent to a change of 3.25 inches in the lake level. As this difference would diminish rapidly for lower stages of water, it is probable that the low water level of the lake would never be affected to exceed two inches and a half by withdrawing 10,000 cubic feet per second from Lake Michigan for the proposed waterway. The lowest stage occurs in winter, when navigation is closed.

The area of the surfaces of Lakes Huron and Michigan is 46,250 square miles, as given by the latest determinations. Ten thousand cubic feet of water per second taken from Lake Michigan for waterway purposes would lower the surface of these two lakes 3 inches per year if considered independently of the natural outlet and without inflow or evaporation. The annual rise of the lake usually covers a period of about four months, and consequently the variation in the yearly fluctuation of the lake surface due to withdrawing such a volume of water could not exceed one inch.

There are other physical features of the river system taken as a whole that have a modifying influence on the slope and velocity of the river. The water level of Lake St. Clair is to a great extent governed by the depth of water at the Lime Kiln crossing near the mouth of the Detroit River, and as a change of 10,000 cubic feet per second in the discharge of the river would produce but a very slight change in the water level at this point, the level of Lake St. Clair would remain practically unchanged, and consequently change of slope in the river due to change of level of Lake Huron would be distributed above this point.

When we consider that hourly fluctations of the lake surface of from 6 to 30 inches in amplitude are constantly taking place, it is evident that the withdrawal annually of a volume of water from Lake Michigan, equivalent to 3 inches in depth over the surfaces of the two lakes would not be appreciable in any ordinary set of gauge readings, and would certainly have but little effect on the depth of water in the connecting waterways.

Any investigation of this subject that may be made in the future should not only take into account the discharge of the St. Clair River at various stages of the lake level, but also the slope of the different sections of river for each stage. Self-registering gauges should be established at the foot of Lake Huron, at foot of rapids in head of river, at head of delta above Lake St. Clair, at the St. Clair flats canal and at the head of Lake Erie, and the zeros of all the gauges connected with lines of level.

DISCUSSION BY L. E. COOLEY, MEMBER OF THE WESTERN SOCIETY OF ENGINEERS.

Apart from any practical application, a comprehensive series of discharge measurements of the outflow of the lakes would be of great scientific interest. Such measurements could not be discussed except with the aid of some such determination of the slopes in the connecting rivers as suggested by Mr. Wisner. So far as the effect on the level of the lakes being a matter of practical moment, the subject may be dismissed.

When a waterway to carry 10,000 cubic feet was first proposed, some three years ago, naturally, the effect upon the lake levels was the first question to suggest itself. I then concluded that this would not exceed three to four inches and did not think it judicious to raise the question. It has been raised, however, and made much of by those opposed to the project, so it seems necessary to discuss it publicly.

In a recent pamphlet, "The Lakes and Gulf Waterway," I have considered the data briefly in a variety of ways, with the general conclusion that a change of one foot in level would be equivalent to a change of 30,000 to 40,000 cubic feet per second in the discharge of the St. Clair River. These deductions were made independent of any considerations introduced by changing slopes. I append this discussion as part of my remarks upon this subject.

Mr. Wisner's treatment of the problem indicates what may be called a throttle at Port Huron, a sort of reducing valve which regulates the outflow without greatly altering the level in the river below. The observations taken seem to be in harmony with this view, an upward fluctuation in Lake Huron transmitting an increased velocity and discharge to the river below rather than variation in stage. If this be so, then any minor change in lake level, so far as the river system is concerned, is practically masked in the Port Huron rapids.

Suppose, as an extreme case, that in place of 10,000 cubic feet per second, it is desirable to withdraw a volume so large as to lower the level of the lakes by one foot, to what extent would the interests of navigation be injured ?

So far as Chicago and vicinity are concerned the benefit of a foot less height would be so great as compared to the small expense of deepening the harbors, that it would be looked upon as a blessing. The same would be true of Milwaukee and of every harbor of which I have knowledge about Lakes Michigan and Huron. The chief injury would be at the St. Clair flats and at the mouth of the Detroit River, and the cost at these places of another foot (it would probably be less) would be a comparatively moderate item. In fact, the cost of an additional foot for navigation at all the harbors of the two lakes and in their outlet would not be an amount of great moment. So we may conclude that the effect of withdrawing 10,000 cubic feet per second is not material.

In 1881, the Canadian Government was engaged in deepening the rapids of the St. Lawrence below Ogdensburg, from 10 to 16 feet, adding from 6 to 8 per cent. to the free channel. Much alarm was occasioned at Toronto and other Canadian ports through a fear that the level of Lake Ontario would be greatly lowered, and a similar interest was felt upon the American side. The question was finally referred to the Engineer Department through Senator Miller, of New York, and reported upon by General Comstock and Colonel MacFarland, the latter very elaborately. (See Report Chief Engineer, 1882.) The conclusion was that the effects would extend to no great distance, and that the level of Lake Ontario would not be impaired.

Similar cases are presented at the Lime Kiln crossing of the Detroit River, where the depth has been increased from 13 to 20 feet, and at the St. Clair flats, which have been deepened from 9½ to 16 feet, and where a farther deepening to 20 feet is now in progress; also, in the St. Mary's River, which had a depth originally of 9½ feet, since increased to 16 feet, and now in progress of deepening to 20 feet in a greatly shortened channel.

It is but fair to say that these cases are not strictly parallel to the one under discussion. Undoubtedly, an enlarged or less obstructed channel gives a freer discharge and affects the surface in the vicinity like an additional outlet. It distributes the local slope over a longer reach and thus increases the general velocity through the stream and its capacity for discharge. This of course will lower the surface of any lake from which the stream flows. The effect, however, diminishes up-stream from the locality, and at some distance, depending upon the size and character of the stream, may be considered as nothing; so the effect on a lake at a sufficient distance above is of no interest, except to a technical discussion in hydraulics.

These cases are cited to show how easy it is to raise needless alarm and to prejudice an important public enterprise. The data is certainly sufficient, from any scientific point of view, to satisfy the engineer that any effect upon the level of the lakes by the proposed waterway will never be appreciated by the navigator.

Gen. James H. Wilson, who prepared the project for a steamboat channel of seven feet depth from Lake Michigan to the Mississippi River in 1868, and which has been before Congress ever since, says in a letter published in "The Lakes and Gulf Waterway" brief, that "I am satisfied that such a discharge (10,000 cu. ft. per second, as now proposed) will not appreciably disturb the lake level." Mr. Robert E. McMath, in a paper printed in the August number of the Journal of the Association of Engineering Societies, concludes "that the effect upon the lakes, that is, upon the depth at entrances to harbors and through the St. Clair channel, will be practically nothing." Mr. McMath was for twenty years upon the improvement of the Mississippi and Illinois rivers, and was General Wilson's principal assistant when he was in charge of the latter stream.

General Wilson, Mr. McMath and Mr. Wisner, from long and intimate familiarity with the conditions affected by the proposed water-way, should be well prepared to apply theoretical considerations. Every one who has considered the data seems to reach the same conclusion.

From my own point of view, however, I am so fully convinced of the good effects of 10,000 cubic feet per second added to the low-water volume of the Mississippi, that I believe that it will be only a few years after the construction of this waterway before we shall have to consider the effect of abstracting a volume three or four times as large. It may be said here, that it is quite within engineering resource to turn the entire discharge of the lakes in this direction, but no man would care to venture his reputation in discussing such a proposition at this time.

From "The Lakes and Gulf Waterway" brief:

[Further consideration, see "Data, etc.," at end of discussion.

APPENDIX NO. 8.—LAKE LEVEL EFFECTS.*

Lakes Michigan and Huron are so connected by the Straits of Mackinaw as practically to constitute one lake. Lake Superior is at a higher elevation, or is independent except so far as it is tributary to lakes Huron and Michigan. The waters of the three lakes drain through the straits called the St. Clair and Detroit rivers, some 85 miles long and with slight fall to Lake Erie. Whatever water is taken from Lake Michigan by the proposed Chicago outlet will diminish by that amount the quantity flowing out by the St. Clair River. What will be the effect on the normal elevation of the lakes?

The data for a complete discussion is insufficient. It is found principally in the reports of the Lake Survey (Chf. Engrs., 1868, 1869, 1870 and 1882). The following table is compiled from the latest and most authorative sources. The areas of basins and of lake surfaces are computed to the localities where discharge observations were made, viz., St. Marie, St. Clair, Lewiston and Ogdensburg, and include the intermediate lakes and rivers with their tributary water-sheds. The rainfall and evaporation are computed on these areas for the year 1868.* The areas are given in square miles and the volumes in cubic feet per second.

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* This extract is corrected for the latest figures.

LAKE.	Elevation above mean tide.	Mean discharge	Total basin.	Lake surface.	1868.	
					Rainfall basin.	Evaporation lake.
Superior.........	601.8	86,000	82,800	31,200	171,430	27,690
Huron & Mich..	581.3	225,000	116,600	46,400	251,450	59,890
Erie.............	572.9	265,000	41,835	10,435	100,340	14,310
Ontario..........	246.6	300,000	30,790	7,280	73,840	9,590
Totals.......	....	....	272,025	95,315	597,060	111,480

The data indicate large variations in discharge from effects of winds and other causes, but give little clue as to the quantities at extreme low water and extreme high water. Extreme low water is probably 20 to 30 per cent. less, and extreme high water 20 to 30 per cent. more. These extremes are reached only in a long series of years, giving changes of level on the three lakes of 3 to 4½ feet. The mean annual fluctuation for 30 years has been for Superior 1.2 feet; Huron and Michigan, 1.34 feet; Erie, 1.55 feet; and Ontario, 2.07 feet; with probable variations in discharge of 10 to 15 per cent. from the annual mean.

For present purposes assume the discharge approximately as above, and the Chicago outlet opened for 10,000 feet per second. This would be less than 4½ per cent., but assume it at that amount, leaving 95½ per cent. to go down the St. Clair, after the level is adjusted to the new conditions; the ultimate lowering will be just the amount required to give the St. Clair River a capacity for 10,000 cubic feet less water.

It is a fundamental principle in hydraulics that in any stream the capacity for discharge will increase faster than the mean depth, or, for a given change in discharge, the change in mean depth will be less. If the stream is of uniform prism and unchanging grade, long established formulæ may be applied, viz.: that the new mean depth is the two-thirds power of the new discharge. The new discharge being 95½ per cent. gives the new mean depth at 97 per cent.—a diminution in mean depth of 3 per cent.

The channel is, however, irregular, of varying width and cross-section.

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* Elevations are from final report of the U. S. Lake Survey (Primary Triangulation, etc.). Discharges, areas of basins and lake surfaces are compiled from tables by Mr. L. Y. Schermerhorn, republished by Mr. Chas. Crosman in his chart giving the fluctuations of the lakes for thirty years and much other useful information (Milwaukee, 1888). To these data are added 40 square miles water surface and 1,950 of basin for the St. Lawrence above Ogdensburg. Rainfall and evaporation are computed from data by D. Farrand Henry in reports of U. S. Lake survey. Various estimates have been made of the lake surfaces, but those computed by Mr. Schermerhorn from the final charts are doubtless as correct as present information permits. Mr. Wisner furnishes the following estimates by different authorities of the proper lake surfaces:

LAKE.	Johnson's Encl.	Appleton's Encl.	Prof. Mitchell's Atlas of Mich.	L. Y. Schermerhorn.	U. S. Charts, lake survey.
Superior...........	31,400	32,000	32,000	31,200	31,200
Michigan...	25,600	22,400	20,000	22,450	22,450
Huron..............	23,800	21,000	20,000	23,800	15,760
Erie........... .. .	10,000	9,600	6,000	9,960	9,960
Ontario...........	7,300	6,300	....	7,240	7,240

Last column omits Georgian Bay from area of Lake Huron.

The experience on Western rivers indicates that the new mean depth will be a less power of the new discharge. If the one-half power be assumed, the diminution in mean depth will be 2¼ per cent. The St. Clair River is a stream of unusual regimen, and it is probable that the truth will be more nearly represented by the one-third power, giving for a diminution of 4½ per cent. in discharge, a diminution of 1½ per cent. in mean depth.

The mean depth in this case is that for an indeterminate section of the river below Lake Huron. What length is involved in the discussion will not now be considered. This mean depth is the average area of the cross-section of the stream divided by its average width, and for the St. Clair River, as judged from the published charts, will be nearly 25 feet. This will give a change (1½ per cent.) of 0.37 foot, or nearly 4½ inches.

Taking the mean depth for the whole stream as a uniform prism and without regard to ruling points gives the largest possible results.

To approach the matter comprehensively would require observations taken with the special view of ascertaining the discharge at different stages of the lake under varying conditions. So far as the observations can be used in a direct determination, they appear to indicate that the change of level for a difference of 10,000 cubic feet per second will be somewhere between 0.2 foot and 0.4 foot—say 1 foot for 30,000 to 40,000 cubic feet per second.

Some considerations may be presented, as showing how difficult it may be to detect or value any effects produced.

Considering the combined area of lakes Huron and Michigan as a reservoir (46.400 square miles), 1 foot of water will represent a discharge of 10,000 cubic feet per second for 4.10 years; or 2.93 inches that for one year. One foot of water on Lake Superior will represent this volume for 2.76 years; or 4.35 inches that for one year.

The extreme variation in the three lakes, for a series of years, is 3 to 4½ feet, and the ordinary annual variation from low to high water is 1 to 2 feet. There are also daily and periodic variations from wind, change of barometer and other causes, frequently of a foot or more. The surface of the lake is never constant, and can only be determined by observations continued over a period of time.

It is ascertained that changes in wind produce large variations in the discharge through the St. Clair River. The long series of meteorological observations at many stations about the lakes showed that there were great variations in rainfall, and that it was not uniformly distributed over the basin, being sometimes in excess in the upper lakes and deficient in the others, and sometimes the reverse.

These observations also show great variations from year to year in the evaporation.

The evaporation on lakes Huron and Michigan (see table) for the year 1868 would be about 17½ inches, and for 1867 (79,500 feet per second) would be some 23¼ inches, a difference for these two years alone of enough to supply the Chicago channel for two years. The difference on Lake Superior for these two years was nearly a year's supply.

On account of the many conditions involved, the great changes in lake level from complex causes, the variations in meteorological conditions—rainfall, winds, evaporation, vegetable growth, etc.—which it is impracticable to value closely, it is doubtful if long continued observations for lake elevation would detect a change and assign its amount. In other words, the abstraction of 10,000 cubic foot per second, so far as its effects are concerned, is not a matter of material moment, and might never be perceived.

An interesting question arises as to the amount that may be abstracted without raising broad questions of perhaps an international character, If the records for the last thirty years are studied, it will be found that Lake Erie begins to rise first in the spring, followed by lakes Michigan and Huron, and later by Lake Superior, which reaches high water in August or September. When 200,000 cubic foot per second passes the St. Clair River, the lake is still nearly one foot above low water. Certainly any amount of water drawn from the lakes without impairing the natural elevations below this one foot would not be injurious to navigation, and would reduce high water and its destructive tendencies.

Suppose that works to regulate the outflow of Lake Superior be placed at the Sault Rapids, a matter of no great difficulty and of comparatively small cost. While supplying a certain minimum quantity to the St. Mary's River,* the high water can be retained until later in the season, or in place of coming in on top of the high water of lakes Huron and Michigan it may come in after it has run out. This may probably be done without injury to Lake Superior interests.

If proper observations for discharge at various stages of the lakes existed it would be possible, from the thirty years' records of stage on all the lakes, to deduce closely enough for all practicable purposes the regulative influence which could be attained by controlling the outflow of Lake Superior. It is very probable that such a study would show the feasibility of diverting not less than 30,000 cubic feet per second to the Mississippi, reducing the high water fluctuations in all the lakes below Superior, and without impairing—perhaps, on the contrary, improving—their levels for navigation. It is virtually to conserve the surplus above that required for a moderate stage of water. How far such regulation may be justified with a view to a large volume of water to the Mississippi is presented in the next appendix.

As an engineering question, it is quite possible to use the lakes as reservoirs to the highest degree desirable, or to even increase their discharge by diverting thereto streams which now flow to western rivers. This is not now a question for practical consideration.

Note.—There appears in the Detroit *Free Press* of January 8 and 11, two interesting communications in regard to the effect upon the level of Lake Superior of the proposed water-power canal at Sault Ste. Marie.

Mr. D. Farrand Henry states that the canal has been begun with a depth of 12 feet and a width of 100 feet, and that it is now proposed to make the width 250 feet, thus taking from the rapids about 10 per cent. of the outflow of Lake Superior. The effect of the smaller canal he regards as immaterial, but he states that the larger channel will lower the water above nearly 6 inches and diminish by that amount the depth for navigation in the U. S. Canal and the river above.

Gen. O. M. Poe, in charge of the government works from Lake Superior to Lake Erie, in his reply deprecates any alarm to the interests of navigation, and, admitting for the sake of argument the truth of Mr. Henry's conclusions, says: "A simple, easy and inexpensive way of remedying the evils which the writer of the article seems to fear, would be to reduce the cross-section of the river by building a spur-dam at the head of the rapids, thus intercepting an area equal to, or even considerably less than, the cross-section of the water-power canal;" and again, that it "surely would not require a construction of any great magnitude or cost; nor would it tax the ability and resources of the engineer to an overwhelming degree."

The application is obvious.

DISCUSSION BY LEWIS M. HAUPT, M. A. S. C. E., ENGINEERS' CLUB OF PHILADELPHIA, ETC.

However great the benefits to be derived from a public work may be, there will always be found an opposing element, because the proposed improvement may divert traffic from existing channels or means, and so apparently affect certain interests injuriously.

If there is a possible objection, either real or imaginary, which can be urged to prevent the consummation of the project, the parties interested in opposing will give expression to it, and the agitation concerning the injurious effect upon the level of Lake Michigan, which would result from withdrawing from it 10,000 cubic feet per second, appears to be such a *bête noire.*

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* The fall in the St. Mary's River from the rapids to Lake Huron is but two feet, and if it were desirable to, at times, entirely arrest the flow, it is practicable to conform the improvements at the Sault to this condition.

I have read the interesting and valuable papers on the subject contributed by Messrs. Cooley, Wisner and McMath, and have nothing to add to their exhaustive, theoretical demonstration, but there are a few practical considerations which do not appear to have been fully developed in this discussion which I think may have weight in the popular consideration of the subject. They refer more especially to the actual fluctuations of the lake's surface as affecting navigation. It has been shown that the amount of water required to maintain navigation in the Cooley channel (150 × 24 feet) might reduce the level of the lake three inches in one year or one inch in four months. That this would be inappreciable in its effect on navigation will be strikingly evident when we come to examine the physical changes of level from natural causes.

The extreme fluctuation in the level of Lake Michigan from 1836 to 1887 inclusive, as shown by the record furnished me through the courtesy of D. J. Whittemore, C. E., are found to be as great as 5.5 feet. The maximum elevation recorded was in June and July, 1838, when it was 4 feet above the city datum (Milwaukee), and the minimum was in February, 1847, when it stood at 1.5 below the zero. The annual fluctuations are not so great, being limited to about 2½ feet. The lowest water invariably occurs during the winter season, when there is no navigation, and the highest during June and July. In February of 1875 and 1880 the water level fell to the datum plane, but it is only the lowest water during the season of navigation that affects this question. The summer stage usually varies from 1 to 2½ feet above zero, but in the year 1872 it was unusually low and constant, and stood as follows: April, — 0.4; May, — 0.1; June, July and August, + 0.3; September, + 0.25; October, + 0.2.*

At no time since has the water been so low. It will be seen, therefore that the withdrawal of a few inches of water throughout the year would in no way affect the commercial interests of the lakes, and, as Mr. Wisner very justly concludes: "When we consider that the hourly fluctuations of the lake surface of from 6 to 30 inches in amplitude are constantly taking place, it is evident that withdrawing 3 inches in depth from Lakes Michigan and Huron would not be appreciable in any ordinary set of gauge readings, and would certainly have but little effect on the depth of water in the connecting waterways."

Before any injurious effect could be manifested in the St. Clair canal or river it would be necessary to reverse the direction of the currents in the straits of Mackinaw and Lake Michigan. I can imagine no public improvement which would be a better investment for the surplus or do more to promote the general interests of the whole country than the enlargement and completion of the Great Belt Waterway.

DISCUSSION BY CLEMENS HERSCHEL, MEMBER OF THE BOSTON SOCIETY OF CIVIL ENGINEERS, AND OF THE AMERICAN SOCIETY OF CIVIL ENGINEERS:

If, in conformity to the invitation of the Secretary, I say anything upon the paper by Mr. Geo. Y. Wisner, entitled the "Effect of the Proposed Lakes and Gulf Waterway upon the Level of the Great Lakes," it will only be to illustrate how such a subject impresses a hydraulic engineer, habitually working in quite another section of the United States, and dealing with very different bodies of water.

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* The gauge records of fifteen years show the Chicago datum to be 0.691 foot below the Milwaukee datum. Chicago datum is low water summer of 1847, as adopted by the Illinois and Michigan Canal Commissioners.—EDITOR.

It seems to me that all considerations of the effect of the amount of annual rain-fall, of the varying distribution of that rain-fall throughout the year, of the annual and monthly evaporation, of the effects of the winds, tides and other disturbing causes, may, in the consideration of the precise subject above written, be left out of account.

These things we have always with us, and shall have in the future, not much less, nor much more, than we have had in the past.

Given a new outlet to Lake Michigan, carrying 10,000 cubic feet per second to the Mississippi River, or, we will say, 4.5 per cent. of the discharge of the outlet of Lakes Michigan and Huron combined, and naturally diverting just that much from the St. Clair River, it is evident that in only two ways can an equilibrium, or régime, be re-established.

1. The two lakes may be allowed to lower a certain small amount, until the discharge of the St. Clair River become 4.5 per cent. less than it was before, or

2. The area of cross-section of the St. Clair River at any ruling point or points may be reduced, artificially, until its discharge become 4.5 per cent. less, at times when the present lake levels obtain.

As regards the first proposition, I judge it to have been fully analyzed by Mr. McMath, p. 4 of his paper read before the Engineers' Club of St. Louis, May 30, 1888, and summed up when he says: "Lake Huron (and, of course, Lake Michigan) cannot possibly be lowered more than by the trifling quantity required to adjust the slope of the St. Clair River, now only one-half inch to the mile, to the volume (of its discharge) diminished by five per cent. * * * The conclusion is therefore safe, that the effect will not be noticeable, except as a result of a long series of observations, such as were required to establish the fact of a tide in the lakes."

As regards the second proposition, nature will to some extent work in the way indicated. For, given a reduction of 4.5 per cent. of the discharge of a stream having only one-half inch of slope to the mile, the tendency will be for that river by natural accretions to reduce its own cross-section, until the area of channel shall again be in conformity to the amount it is called upon to discharge.

Going to extremes of argument, I can conceive of a sufficient diversion of water from the St. Clair River and into new outlets, to cause the St. Clair Flats naturally and by accretion to become dry land, and a resultant material raising of the levels of Lakes Michigan and Huron to be brought about, by the method (paradoxical as it may seem) of diverting the waters of the two lakes to new outlets.

At all events, it seems to me, that should it be desired, religiously and with precision, to maintain the two lakes at their present mean level, a diminution of the discharge of the St. Clair River will offer the means for the accomplishment of such an end, and the ordinary processes of nature will co-operate in such an endeavor.

Four and one-half per cent. of the discharge of the St. Clair River is less than 4 per cent. of the Niagara, and 3⅛ per cent. of the St. Lawrence, and to maintain the levels of Lakes Erie and Ontario with the same precision, the discharge of the Niagara and of the St. Lawrence rivers would have to be diminished, in the same way or ways, to the extent of the small percentages above given.

DISCUSSION BY J. B. JOHNSON, MEMBER OF ENGINEERS' CLUB OF ST. LOUIS, MEMBER OF AMERICAN SOCIETY OF CIVIL ENGINEERS.

The effect on the level of Lakes Michigan and Huron of extracting 10,000 cubic feet per second at Chicago, depends wholly upon the outlet conditions at Port Huron. It so happens that these conditions are such as to concentrate the controlling functions within a mile and a half of the outlet of the lake. We find here a greatly reduced cross-section, with a corresponding high velocity and steep slope, followed below with a large channel, low velocity and small slope. So emphatic is this natural development that the hydraulic problem reduces itself more nearly to the case of flow over a submerged weir than to the case of flow in an ordinay natural channel. The similarity to a submerged weir comes not only from the engorged condition of the channel here with reference to that below, but from its short length and from the still water of the lake just above it.

Evidently the true solution of the problem is to measure the discharge of the St. Clair River as near the head as practicable, and compare these discharges with simultaneous gauge readings at Lakeport, for instance, some 10 miles above the foot of the lake. There are permanent benches at this point, and it was here that the gauge was established which was used for determining the mean level of Lake Huron, and with which the line of precise levels from the sea was connected. Then by noting the variation in discharge for given changes in level of the lake it would immediately appear what change of lake level would correspond to a change of discharge of 10,000 cubic feet per second.

In the absence of such observations, however, it may be worth while to determine, as near as may be, its probable amount. In such a study I should prefer to approach the problem through a submerged weir formula rather than through a uniform flow formula.

Taking Mr. Wisner's figures as to volume, velocity and distance, but not as to slope, we have:

Discharge at Port Huron = 225,000 cubic feet per second.
Width of engorged section = 750 feet.
Velocity here = 7.5 feet per second.
Distance of this section from lake = 2,500 feet.

From the data given we find the mean depth must be 40 feet at the narrow section.

Probably the most acceptable submerged weir formula is that of Fteley & Stearns, which is

$$Q = c\ l\left(d + \frac{d^1}{2}\right)\sqrt{h} \qquad 1)$$

where

Q = discharge in cubic feet per second.
c = numerical co-efficient = 3.3 for our case.

l = length of weir, or width of channel.
d = depth of water on weir above (in lake).
d^1 = depth of water on weir below (in lower river).
h = fall across weir $= d - d^1$
All dimensions being in feet.

For the case in hand, everything here is known except h, the fall from the lake level to the enlarged channel below. We can, therefore, compute this from the above equation. Doing this we find (calling $d^1 = 40$ feet)

$$h = 2.136 \text{ feet.}$$

Mr. Wisner has taken this at 1.9 feet. The submerged weir formula here used holds for a very short submerged weir (measured in the direction of flow), and for flow from nearly still water into nearly still water. Two of these conditions are not fulfilled in our case. The weir is long in the direction of flow, and the current below is comparatively strong. The long weir would require a greater fall than the formula would give, but the free escape of the water below would result in a less slope than shown by the formula. It is impossible to accurately evaluate these two conditions, but since they are in opposite directions, and are probably nearly equal, we will here assume that they balance, and suppose that the fall due to the submerged weir condition is, as given above, 2.136 feet.

To find the change in lake level, d, due to a change in volume of 10,000 cubic feet per second, we can substitute $d - d'$ for h in equation (1), and obtain

$$Q = c\,l\left(d + \frac{d'}{2}\right)\sqrt{d - d'} \qquad (2)$$

Differentiating this equation for d and d' as independent variables we obtain:

$$\Delta Q = c\,l\left[\frac{(3\,d - \frac{3}{2}\,d')\,\Delta d - \frac{3}{2}\,d'\,\Delta d'}{2\sqrt{d - d'}}\right]$$

$$\text{or } \Delta d = \frac{4\sqrt{h}\,\Delta Q + 3\,c\,l\,d'\,\Delta d'}{3\,c\,l\,(2\,d - d')} \qquad (3)$$

Where ΔQ, Δd, and $\Delta d'$ represent the changes in the discharge, lake level, and stream level below the weir section respectively.

If in this equation we let $h = 2.136$; $\Delta Q = 10{,}000$ cubic feet; $c = 3.3$; $l = 750$ and $d' = 40$, then we have:

$$\Delta d = \frac{11.8 + 60\,\Delta d'}{66.4} \qquad (4)$$

Now it is known that $\Delta d'$ will be quite small for this is the change of level in the river below the engorged reach at Port Huron.

If $\Delta d' = 0.0$, then $\Delta d = 0.177$ foot $= 2\frac{1}{8}$ inches.
If $\Delta d' = 0.05$ feet, then $\Delta d = 0.223$ feet $= 2\frac{5}{8}$ inches.
If $\Delta d' = 0.08$ foot, or 1 inch, then $\Delta d = 0.25$ foot $= 3$ inches.

It is not probable that the river below the rapids at Port Huron will fall more than from $\frac{1}{2}$ inch to 1 inch. In which case the lowering of the lake would be from $2\frac{1}{2}$ to 3 inches.

DISCUSSION BY WM. PIERSON JUDSON, MEM. AM. SOC. C. E., MEMBER COMMITTEE ON TRANSPORTATION ROUTES, OSWEGO BOARD OF TRADE.

THE LOWER LAKES AND THE NIAGARA SHIP CANAL AS AFFECTED BY THE PROPOSED LAKE MICHIGAN AND MISSISSIPPI WATERWAY.

The proposed Lakes and Gulf Waterway, connecting Lake Michigan and the Mississippi River across the Chicago "divide," is a project whose execution would vastly affect lake commerce.

The papers by Mr. L. E. Cooley, by Mr. Robt. E. McMath, by Mr. Ossian Guthrie and by Mr. Geo. Y. Wisner, seem to leave nothing unsaid in favor of the project, and to remove any fear of an important lowering of the upper lakes, by the opening of the proposed waterway. Any perceptible lowering of lakes Erie and Ontario by it, may be put wholly out of the question.

As my interests for twenty years have been identified with the harbors on the lower lakes and on the River St. Lawrence, and also more recently with the proposed Niagara Ship Canal, I need therefore only consider the proposed Lakes and Gulf Waterway as it may affect these interests, or may divert commerce rather than water from the lower lakes and from their canals.

That a large amount of lake commerce would use the proposed waterway to the Gulf is beyond doubt, but this diversion from the present route would probably be offset by a general growth of business resulting from the increased facilities.

If the proposed 20-foot Niagara Canal to Lake Ontario, and the 9-foot enlargement of the Oswego and Erie canals to the Hudson are also made, this direct eastern route, with its cooler climate, need fear no competition from the longer Southern route to the Gulf. The main flow of commerce must be by the most direct line to New York, the focus of the country's business interests.

Even the present Erie Canal route from Buffalo could probably hold its share of the upper lake business; but still better could this eastern route do when it has the Niagara Canal to take the largest upper lake steamers to Oswego, where they could tranship their cargoes to barges, 146 miles nearer to New York than now at Buffalo.

From this point of view, I can only see that anything which will extend the channels and range of lake commerce must be for the ultimate good of the system as a whole; and that so far from the advocates of the Niagara Ship Canal opposing this proposed connection of the lakes with the Mississippi, they should rather further it in every way, regarding it as the completing link in the same chain, of which a deep-water United States canal around Niagara would form a part.

Each of these works would but make the other the more necessary.

It will be quite enough that the proposed Gulf waterway should pass the largest lake vessels without their loads, as suggested by Mr. McMath, thus permitting them to go down the Mississippi into Southern water for the winter. The increased range will be a great gain, which vessel owners will be quick to appreciate.

The military advantage of such an interior route to the sea would be important, and would go far to remedy the present lack of any effective defense of our Northern frontier, where our few forts are mere relics, For the large 20-foot 3,000-ton steamers of the future lake commerce, it seems useless to consider deep canals to provide for carrying their full loads beyond the limits of actual lake navigation; or to attempt to take such steamers, loaded, nearer to the Gulf than Chicago, or nearer to New York than Oswego.

No large, seaworthy steamer, equipped to encounter lake gales, could afford to carry this costly and idle equipment through hundreds of miles of inland canals and rivers, whose scant depths would greatly impede their speed and management.

If the Erie Canal and the Hudson River had, to-day, 20 feet depth from Buffalo, or from Oswego, to New York, the lake steamers could not afford to use it; their freight would, in that case as now, be transshipped to barges which could handle it in the canal at less cost, and at less risk in transit.

The lower lake interests should, I think, join heartily with Chicago and the West in forwarding the proposed lake and gulf waterway; expecting an equal liberality from its friends toward the kindred Niagara Ship Canal project.

DISCUSSION BY WALTER P. RICE, MEMBER CIVIL ENGINEERS' CLUB OF CLEVELAND.

Press of business prevents my giving the thought or attention to the subject that I would like to, or that it merits, but I am willing to make the following fugitive comments.

Mr. George Y. Wisner, in his able paper on this subject, has correctly stated the relations between the elevation of the lake surfaces and the volume of rainfall on the drainage area, amount of evaporation and outflow of this great river system.

In close connection, although "relative," comes the consideration of the effect produced by the gradual extinction of the surrounding forests. This would undoubtedly lessen the actual amount of rainfall and increase the height of flood stages; in other words, increase the actual amount of the fluctuations—*i.e.*, the difference between the maximum and minimum stages. This effect is, however, relative and *within our control.*

Accepting the estimate of a withdrawal of 10,000 cubic feet per second, or at the rate of 2.9 inches per year. It becomes evident without going into the details of effects produced by readjustment of slope of the St. Clair River, which are insignificant, that the annual rise of the lakes from 12 inches to 16 inches in amount, the fluctuations of the past, marking from the highest annual rise to the lowest a difference of 6 feet 9 inches, and the hourly fluctuations due to winds, varying atmospheric pressures, etc., in amount often exceeding one foot (although these would only have local bearing), all these are so much greater in magnitude that no fears need be entertained about the withdrawal of 3 inches per year. Besides, the straits and channels connecting the system of great lakes have not the capacity to immediately discharge surplus waters, and if the lake level is lowered by the proposed canal, one of the first efforts of the flood stage would be to replace said loss—Nature striking her equilibrium. As confirmation I quote the following from Elisée Reclus: "The gauges used at Geneva established the fact that the discharge of the Rhone at its issue from the lake is at its maximum 753 cubic yards; now, as the various affluents of the lake supply more than 1,400 cubic yards during their highest floods, it is evident that the Lake of Geneva acts as a complete regulator, retaining one-half of the inundation water which it subsequently empties down gradually when the tributaries retire to their usual level." Over, and above all this, if it were conceded that the effects would be detrimental, it would still be within the power and skill of the engineer to remedy. Finally, I am decidedly of the opinion that the effect on the levels of the lakes has no practical significance.

DISCUSSION BY D. FARRAND HENRY, MEMBER AMERICAN SOCIETY OF CIVIL ENGINEERS.*

The lakes are great reservoirs nearly level, but subject to many fluctuations, both periodic and secular. The difference in level between Detroit and Chicago, as shown by the Michigan Central Railroad survey, is 10½ feet, of which at least 8 feet is in the rivers between Port Huron and Detroit.

The discharge, as shown in my report on the outflow of the lakes, is about 48 per cent. of the rainfall on their surface and on the water-shed, and the fluctuation extending through several years is evidently dependent on the amount of rainfall, but often not noticeable until the year following, as shown in a profile of the curves of lake level and rainfall in one of my reports on the meteorology of the lakes.

Another change of level is due to atmospheric pressure. At Grand Haven and Milwaukee the difference of level due to this cause—after the wind effect was eliminated—was often over a foot, corresponding with the rise and fall of the barometer.

When the wind acts with the pressure the effect is much greater. Between Monroe and Erie on Lake Erie there was often a difference of 6 feet in the water level due to these causes acting simultaneously. Of course such changes of level cause currents in the lakes, and I have observed a current in Lake Superior in the open lake of at least three miles per hour. When stationed at St. Ignace I cut holes in the ice covering the Straits of Mackinac about a mile from shore and observed the currents. The 'direction at such times as I measured them was westward into Lake Michigan, and once was fully three miles an hour. The fishermen there in winter set their nets by cutting a line of holes in the ice, and passing the net from one to the other, and of course lift them in the same way. Once that winter when they tried to lift they found the current so strong that they could not draw in the net against it, and they had to wait till it ceased. Of course the true current through the Straits into Lake Huron must be very small, as they are over four miles wide and 250 feet deep.

There are other fluctuations whose cause is as yet obscure. At Sault Ste. Marie a change of level of over six feet has been observed, and once at Milwaukee a wave rushed up the river from the lake whose amplitude was estimated at over seven feet.

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* Mr. Henry was greatly pressed for time in preparing this matter, and trusted to his memory for his facts.

How, then, are the rivers (so-called) connecting the lakes affected by these changes? Where the fluctuations are regular and act through considerable time, they rise and fall the same as the lakes. Thus, during the season of navigation, the variation of level at the Flats is about one foot—nearly the same as it is in Lake Huron. But when the changes of level are irregular and abrupt their effect upon the rivers is limited—shown on the water-gauge, but not otherwise noticeable. In fact, the water-gauge at the flats was as good as a barometer, indicating the approach of storms, though the variations were small and required close reading. Probably the velocity of the current is also influenced by these changes, though not to the extent that Mr. Wisner states. He is mistaken in saying that the velocity observations at St. Clair only occupied one month; they extended over the whole working season of three years, and the large difference he notices was much modified by subsequent observations. The difference there shown is in part due to the fluctuation in the velocity of flowing water even under a constant head, which makes a large number of observations necessary to obtain a true mean velocity, but mainly to the fact that the observations he notes were made with the double float, which was found to be utterly unreliable, and was not used after the first season, being replaced by the telegraphic meter.

The area of the cross-section of the St. Clair, where the observations were made, was a little over 66,000 square feet, or about 1½ acres. At first thought it would seem as if a small fraction of an inch of rise or fall of the 50,000 square miles of Lakes Huron and Michigan ought to materially affect the depth or velocity of the water passing through this limited channel. But the whole chain of lakes must be considered as a great river widened in places, and subject to the same influences which cause certain fluctuations common to the whole system, while there are also fluctuations incident to the wide and deep lakes which do not much affect the connecting channels. Of course the actual observations are too few to fully establish these relations, but they all tend to show that the general rise and fall, due to extended causes, is nearly the same in amount, though differing somewhat in time over its whole extent. So that if the withdrawal of 10,000 cubic feet of water per second at the head of Lake Michigan would only lower the level of that lake and Lake Huron 2½ inches, as stated by Mr. Wisner, then the depth in the channel of the St. Clair and Detroit rivers would be only decreased by the same amount, or about one-fifth of the ordinary fluctuations during the season of navigation, or it might cause a slight decrease in the velocity of the current, amounting to about 0.2 of a foot per second at St. Clair; either of which would practically be inappreciable.

DISCUSSION BY BENEZETTE WILLIAMS, MEMBER WESTERN SOCIETY OF ENGINEERS.

By a careful reading of Mr. Wisner's paper and the discussions of it by Messrs. Cooley and Johnson, it becomes plain that, though an approximation may be made of the lowering which Lakes Huron and Michigan will sustain by the withdrawal of a given quantity of water through a new outlet, no exact determination is possible except by a series of gaugings on the St. Clair River made with a view to such determination. It requires no measurements to establish the proposition that if the channel of the St. Clair River maintains its present proportions, that is, if there is no change in the regimen of the river, the lakes must suffer a decrease of mean elevation by the withdrawal, through another outlet, of any quantity of water, however small. Though the increment of decrease may be lost sight of in the hourly, daily and yearly fluctuations of the lakes, it will exist, nevertheless. It may be smaller owing to the rapids at the upper end of the river than it would be with a different sort of channel, but it cannot, by any method of sound reasoning, be wholly eliminated.

The proper way of determining the change of lake level is by discharge measurements of the St. Clair River extending over the whole range of lake fluctuations, and a comparison of discharges and elevations for different stages. By this means it would be shown, doubtless, that the withdrawal of 10,000 feet per second would affect the high stages of the lake much more than the low stages, but each and every stage would be affected in some degree.

These facts furnish opponents of the plan to drain Chicago by means of a channel through the divide between Lake Michigan and the Illinois River with standing ground from which to assail that measure.

As is usual in such cases, a germ of truth has been made to propagate error of far greater proportions.

In a paper read before the Illinois River Improvement Convention, held at Peoria, October 11 and 12, 1887, Major Thos. H. Handbury, the then Government Engineer Officer at Chicago, used the following language relative to the dangers which threaten the lakes from the proposed execution of the Chicago drainage plan :

" In treating of this question of drawing a large supply of water from Lake Michigan, there is one point of great importance that I do not find touched upon in any of the reports or discussions upon the subject; that is, the effect the withdrawal of so large a quantity of water from Lake Michigan, as is proposed by the Chicago Drainage Commission, is going to have upon the mean level of that lake.

" The discharge of the upper lakes through the St. Clair River has been found to be about 217,000 cubic feet per second. The mean level of Lakes Huron and Michigan is 581 feet above the sea; that of Lake Superior about 20 feet higher. The lower lakes receive their supply from this upper lake and the various streams that empty into them. The discharge is just equal to the supply and the lakes remain at their mean level of 581 feet.

" Now suppose we make another outlet in the bottom, or side, if you please, of this lower reservoir capable of taking off one-twentieth of this supply, which is the amount it is proposed to withdraw, what is going to happen in time to the mean level, to the depth of water in the various harbors, and to the channel of the St. Clair River, which the government is spending so much money to improve ? This is a question upon which the people at the outer outlet of the lakes may wish to have something to say. It is, however, one of a purely engineering nature that can safely be left to a board of disinterested engineers to solve."

Subsequently at a meeting of the Executive Committee of the Peoria Convention held at the room of Judge Prendergast in the city of Chicago for the purpose of considering and formulating a bill to be laid before Congress to secure concerted action of the city of Chicago and the General Government in the improvement of the Illinois and Desplaines Rivers, Major Handbury stated that he estimated that the withdrawal of so large a quantity of water as that proposed by the Chicago Drainage Commission, viz.: 10,000 cubic feet per second, would lower the mean level of the lakes as much as one, to one and one-half feet.

It should be borne in mind in this connection that even if the mean level of the lakes should be lowered as much as a foot it should not prevent the carrying out of the important work proposed, nor would it be wholly injurious. At the worst it would only render it necessary to deepen the lake ports by that amount, while on the other hand many benefits would accrue, particularly to low lying cities like Chicago.

We can safely rest in the assurance, however, that a change in the level of the lake of so great a magnitude will not occur.

Though the data available is insufficient to settle definitely the amount which the lakes will be lowered by the withdrawal of a given quantity of water through a new outlet, it is possible to approximate the truth, and thereby prevent statements so seriously erroneous as Major Handbury's from obtaining lodgment in the public mind pending a proper investigation.

The only report made by the Drainage and Water Supply Commission of Chicago was a preliminary one, in which it was not possible to discuss this subject. It was, however, considered by the Commission, with the expectation that it would be treated of in the final report, which, unfortunately, was never made. The deficiency thus left has been ably supplied by Mr. Wisner's paper and the discussion which it has elicited.

The estimates of the lowering which the lakes will be likely to suffer by the withdrawal of 10,000 cubic feet per second through another outlet—which are as follows: Wisner, 2½ inches at low water, and 3½ at high water; Cooley, 3½ to 5 inches; Johnson, 2½ to 3 inches—doubtless cover the range of the possible variation. At any rate, I believe they may be relied upon as the best obtainable results with the insufficient data to be had. But so long as the question rest upon uncertain or incomplete data we may not be surprised to experience renewed assaults from time to time upon the Chicago drainage plan, and we need not hope for protection from such attacks until the question is finally settled by a thorough hydrographic survey of the St. Clair River, conducted in such a manner as to definitely bring out the facts bearing upon the question.

DATA PERTAINING TO THE OUTFLOW OF THE LAKES.

Considerable research has been made for data pertaining to the problem of ascertaining the effect of diverting any volume of water from the natural outlets of the lakes. This matter is herewith submitted as briefly as possible, with such inferences as it seems to convey, and it may be useful pending any exhaustive determination of the question.

INTERMEDIATE CHANNELS.

The following notes pertain to outlets of the several lakes in their natural order :

St. Mary's River.—Outlet of Lake Superior ; mean discharge, 86,000 cubic feet per second.

The fall from Lake Superior to Lake Huron is 20.5 feet, of which about 18 feet is concentrated in the rapids at Sault Ste. Marie; two feet is distributed over the river below and one-half foot over the river above. So far as the level of Lake Superior is concerned, it is solely determined by the flow at the rapids.

Mr. D. Farrand Henry, who is very familiar with the rapids, furnishes the following memoranda: Length, 3,500 feet; fall, 17½ feet; width, about 2,300 feet; average velocity, 15 feet, when the river is discharging 92,000 cubic feet; mean depth, 2.7 feet, and section, 6,110 square feet. These figures are of course approximate. The international bridge is situated in the deeper water, just above the rapids or where the ice breaks off in winter. The water breaks over a massive sandstone ledge most of the way across.

This ledge constitutes the *virtual sill* or weir which controls the level of Lake Superior. If the rapids be assumed as uniform like a trough, the elevation of the lake above the *virtual sill* will be simply the mean depth in the trough plus the head due to the velocity. For a discharge of 86,000 feet, the mean depth would be 2.58 feet and the velocity 14.5 feet. The head due to the velocity would be 3.28 feet. The elevation of the lake above the sill would then be 5.86 feet, supposably at mean level. Whatever the actual conditions may be, this is doubtless an approximation to the truth.

The zero of any curve representing the relation of discharge to gauge reading should be at the *virtual sill*, and as the conditions approach those of a weir the equation will approach a weir formula. In other words, the discharge will vary with the 1½ power of the elevation above the sill, and, as a weir, the co-efficient will be 2.64.

If the above is assumed as correct, then for changes in level of Lake Superior near the mean level, the discharge will vary 2,250 cubic feet for each tenth of a foot. The mean annual fluctuation of 1.2 feet will represent a discharge varying from 73,000 to 100,000 feet.

St. Clair River.—Outlet of Lake Huron, and carrying the discharge of the three upper lakes ; mean discharge, 225,000 cubic feet per second.*

The fall from Lake Huron to Lake Erie is 8.4 feet, and the distance is 85 miles. The following data in regard to the stream from Lake Huron to Lake Erie is compiled from the published charts which are of too small scale for strict accuracy :

The St. Clair River is sufficiently uniform to permit a tabulation of its principal elements. Sections at regular intervals in each characteristic reach have been computed, and the results are tabulated as follows:

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* Lake Michigan is tributary through the Straits of Mackinaw, which have a minimum cross-section of 1,558,000 square feet. See p. 607, Primary Triangulation, U. S. Lake Survey.

GRATIOT BAR TO MOUTH OF CANAL, 41 MILES.

Reach.	Distance, miles.	Average section, sq. ft.	Velocity, feet per sec.	Width.	Mean depth.	Net width	Net mean depth.	Remarks.
To Port Huron............	2	35,000	6.43	1,300	27.0	900	35.0	See note below
To Vicksburg............	6	51,000	4.40	2,100	24.3	1,700	28.0	
To Marine City..........	14	66,000	3.40	2,600	25.4	2,000	30.3	
To Head Passes..........	7	77,400	2.92	2,840	24.8	2,110	33.6	
In South Pass...........	6	36,000	......	1,600	22.5	1,050	30.0	One channel.
In South Pass...........	4¾	24,000	......	1,140	21.0	660	30.0	One channel.
In Canal................	1¼	....	.....	300	16.0	300	16.0	

The minimum section at Port Huron is 31,000 square feet, with a width of 1,000 feet. This section is 660 feet wide inside the 18 feet contours, with a depth of 42 feet. The velocity would be 7.25 feet.

The river divides into several passes, forming a delta, and reaches Lake St. Clair through a number of mouths. The South Pass is used for navigation, but loses part of its water at the sixth mile, and only a small fraction passes through the canal across the bar. The bars at the several passes do not exceed 7 to 8 feet in mean depth. The mean depths given for the South Pass will apply approximately to the other passes. The combined area and width will exceed that of the river above. What is noted as "net width" and "net mean depth" in last two columns are these elements inside the 18 feet contours of depth. They signify the river as available for navigation.

Across Lake St. Clair to the head of the Detroit River is 17 miles, and the average depth is slightly in excess of 19 feet. The Detroit River is 27 miles long, and very irregular as to its dimensions. No attempt has been made to tabulate its elements.

In the first five miles are two islands and some middle ground. For eight miles, from the upper end of Detroit to Fighting Island, it is quite uniform, with an average section of 87,000 square feet, a width of 2,560 feet, and a mean depth of 34 feet. For the next nine miles to Stony Island, the river is subdivided by islands, and is very wide with doubtless a much larger section.

For the 20 miles from Lake St. Clair, or to within two miles of the Stony Island crossing, the net mean depth will run from 30 to 36 feet.

From about two miles above Stony Island, rock bottom of comparatively shallow depth extends for ten miles or more, reaching well out into Lake Erie. The minimum section on line of bridge at Stony Island is as follows:

	Width.	Section.	Mean depth.
Opposite dock......................	2,500	45,000	18
Stony Island bridge................	1,000	7,000	7
American bridge....................	1,300	19,500	15
Total.........................	4,800	71,500	15

At the Lime Kiln Crossing, immediately below Stony Island, the section is as follows:

	Width.	Section.	Mean depth.
Canadian Channel................	8,300	76,000	9.5
American..........................	2,700	35,000	13
Total........................	11,000	111,000	10

Five miles below Stony Island Crossing, at Bar Point, entrance to Lake Erie, the section is 20,000 feet wide, with an area of 296,000 square feet and a mean depth of 14.8 feet. Over this reach and for three miles farther into Lake Erie, the channel of 18 feet depth is very limited.

Considering the channel from Lake Huron to Lake Erie as a whole, about two-thirds of the total fall of 8.4 feet appear to be concentrated in nearly equal proportions at three localities, viz: Port Huron Rapids, St. Clair delta and in the vicinity of the Lime Kiln Crossing, the balance being distributed over some 50 miles of river. It is evident that these ruling points largely determine the fluctuations in the river and in Lake Huron.

Independent of the general fluctuations due to volume of water which affect the lake and river system as a whole, the level of Lake St. Clair is probably determined in the largest degree by the Lime Kiln Crossing and the slope of river above, or is measurably independent of the fluctuations of Lake Erie. The following considerations bear upon this point.

Owing to its shallowness, meteorological causes produce marked fluctuations upon Lake Erie. The current at the Lime Kilns is sometimes increased to four or five miles per hour. The effect is seen in an estuary mouth of the Detroit River, practically unmodified by the littoral drift. Of course there is comparatively little detritus for a delta formation. The fact that there is a delta at the mouth of the St. Clair, formed by very slow accretion, presupposes freedom from rapid and frequent fluctuations, such as occur in Erie. The delta building material is supplied from erosion in the St. Clair River, still going on, the littoral drift under northerly winds down both shores of Lake Huron, which converge upon the head of the river, and the roily water from storm action.

The discussion would seem then to limit itself to the river from Huron to St. Clair. As the effect of the conditions in any given reach diminish up-stream, the lower reaches of the river will have less weight than those near the lake, and the St. Clair delta less than the Port Huron rapids. As these rapids present a section of radical resistance they are probably most largely determinative of the level of Lake Huron under the general conditions prevailing. (See discussion by Messrs. Wisner and Johnson.)

If the stream were of uniform prism and indefinite length, the general law of variation of volume with mean depth could be applied, the relative effect of any reach remote from the lake not entering. If the stream is of irregular section, but uniform in its general characteristics, the relation would involve higher powers. On the supposition that the river might be sufficiently long and characteristic to be determinative, the volume has been assumed to vary as the third power of the mean depth, the mean depth being taken at 25 feet or less. (See Appendix No. 8, Lake and Gulf Waterway.)

A method of discussion much applied to Western rivers is to determine the relation of volume to gauge height for any locality in question. The origin of all such curves is at that level at which flow would cease if the stream be depleted—the crest of some bar below, or the surface of some body of water into which the stream debouches. In this case, it would be the level of Lake Erie, or it might be the level of Lake St. Clair, or the virtual crest of the delta bars.

If the level of Erie is assumed, the zero of the curve would be 8.4 feet below the head of the river. If the discharge increased uniformly from this level, then the increment for each foot would simply be $\frac{225,000}{8.4} = 25,600$ cubic feet. Such curves involve the second power of the gauge height, and frequently the third. The hydraulic conditions in this case imply a curve of high order. The increment would therefore be greater, and would probably exceed 4,000 for each tenth of a foot near mean level.

If the origin were taken at the level of Lake St. Clair, 5.4 below Huron, the increment would be correspondingly greater. If the level of the delta bars, 12 to 13 feet below Huron, be assumed, the increment would be less.

Niagara River.—Outlet of Lake Erie; mean discharge, 265,000 cubic feet per second.

The Niagara River, as it leaves Lake Erie, opposite Black Rock, is much contracted, and has a rapid fall and high velocity, more pronounced, but not unlike the St. Clair at Port Huron.

This contraction is about two miles long, the average width being 2,000 feet, the cross-section 35,000 square feet, the mean depth 17½ feet, and the velocity 7.6 feet, all as determined from the published charts. The fall in this section is 4 feet. The channel is comparatively large below, and is nearly equally divided by Grand Island from a point five miles from the lake to within three miles of the falls. The distance to the falls is 23 miles by the American channel and six miles less on the Canadian side. The fall from the lake to Tonawanda, some eleven miles, is approximately 7.5 feet, and to the foot of Grand Island 3.8 feet more, giving a grade to the river below Black Rock of about 0.4 feet per mile, and about 0.6 feet per mile to the Canadian channel. Immediately above the falls is a rapid descent of over 60 feet before the final plunge.

The conditions here are much simplified by the positive contraction at Black Rock and the free discharge below. It is apparent that the discharge curve must have its origin near the level indicated by the mean depth and that the variation of volume cannot be less than the 1½ power of the mean depth as in either the weir or mean depth formula, leaving out, of course, the variation in slope.

Small variations in gauge height will be practically the same in mean depth. In comparing discharge to gauge in cases like the present, it is usually found that the velocity varies uniformly while the area of section increases in a somewhat higher ratio—in other words, the discharge varies at not less than the second power of the hight above the origin.

If the second power be applied, the variation will be 3,000 cubic feet for a change of one-tenth of a foot at mean level.

The mean depth at the head of the rapids near the falls cannot exceed 7 to 8 feet. A change in level of Lake Erie would probably not affect the level at this point by over one-fourth. The increase of grade and the large channel below Black Rock are doubtless effective in producing a larger increment. It is known that gales of wind upon Lake Erie produce very large variations at the falls.

St. Lawrence River.—Outlet of Lake Ontario ; mean discharge, 300,000 cubic feet per second.

The following notes in regard to the St. Lawrence are from Maj. McFarland's report.*

At 45 miles from the lake and 5½ miles below Ogdensburg, the river descends the Galop rapids. The fall from the lake to the rapids is stated at about 4.5 feet. while the slope of the rapids is irregular and about 10 feet per mile. The section averages about 250,000 feet and the mean depth about 45 feet down to Ogdensburg. The section diminishes to 115,000 feet and the mean depth to 18 feet in the vicinity of the rapids. The section upon the upper bar is 36,000 feet with a mean depth of 11½ feet; and on the lower bar, one-half mile below, 25,000 feet with a mean depth of 9 feet.

The fall stated above the rapids is based on the average fall for the entire St. Lawrence and is doubtless in error. On the basis of the slopes found in the St. Clair River, it would be almost indeterminate. It is probably less than 0.5 feet, but will be assumed at that figure. The upper bar at the Galop would then be 12 feet below the level of Lake Ontario.

Considered as a weir, the increment would be about 4,000 cubic feet for each tenth near mean level. It is probably greater than this.

DISCHARGE MEASUREMENTS.

During 1867, 1868 and 1869, Mr. D. Farrand Henry, then an assistant upon the Lake Survey, was in charge of parties engaged in measuring the outflow of the several lakes. These measurements were apparently designed to ascertain the mean discharge during these years rather than to discover the variation with stage and cannot be applied with satisfactory results to the latter purpose.

Mr. Henry's experience with double floats led him to devise the telegraphic meter, which he used during the last two seasons. This instrument has since come into quite general use for velocity measurements. Both with the double floats and the meter, however, the observations were largely directed to ascertaining the distribution of velocities in the cross-section. This work was the occasion of a notable controversy with General Abbott (Humphreys & Abbott, Physics and Hydraulics of the Mississippi, etc.), and marks a renaissance in hydraulic investigation. Mr. Henry left the survey before the matter had been finally reduced for a permanent record. Since then great advances have been made in appliances, methods and skill, hydraulic investigations having been vastly multiplied. The accuracy of methods employed in all the earlier observations was greatly overrated, and it is only within a few years that they have been adequate to the studies now required in regard to the outflow of the lakes.

It is apparent that the volume of any stream flowing from any of the lakes will vary with the stage of water in the lake and that the change in volume may be compared to the change in level. If the observed volumes be platted to the gauge heights, a discharge curve may be constructed and its equation found. The origin or zero of such a

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*Rept. Chf. Engrs., U. S. A., 1882, p. 2,470 *et seq.* Effect upon level of Lake Ontario by improving Galop Rapids.

curve, as previously explained, will be at that level at which flow would cease, if the stream were depleted. These observations can be used for this purpose only to a very limited degree.

The observations rarely covered more than a fraction of the cross-section in any one day, and in computing the observations several days, and sometimes the season's work is reduced as a single measurement. Where the discharge is given for each day's work, it is ascertained by comparing the partial discharges with the mean for the season in the same portions of the section. The elevation of water is usually referred to a local gauge.

To utilize these data for the present purpose it is necessary to refer the discharge to the elevation of the lake from which the stream flows. For this the gauge records have not always been available, and it has been necessary to approximate the elevation from the published charts of fluctuations. There are large discrepancies in the individual measurements, due doubtless to change in flow distribution, sudden fluctuations and other causes, so they have been combined in groups for comparison with general lake elevation over a limited period. Such methods can have only the most general value.

The elevations given are referred to the high water of 1838, measuring downward.

St. Mary's River.—One mile below rapids. Mean level of Lake Superior, 3 feet below the assumed high water of 1838.

1867—(See Rept. Chf. Engr. 1868, p. 949 *et seq.*) Method of observation, by double floats.

From July 3 to August 5 inclusive, observations were made on 24 days and all reduced as a single measurement. There was little change in gauge height or volume.

Level of Lake Superior..	2.20
Discharge per second..............	90,783 cubic feet.

The attempt to separate the data as presented into groups is unsatisfactory. Some of the comparisons indicate a volume of 18,000 to 20,000 for a change of one foot in level, while others are not significant. This is, however, close to the amount indicated by the hydraulic conditions at the rapids.

The level of the lake was some 0.8 feet above mean level. This would indicate the discharge of Lake Superior at about 75,000 cubic feet, or less than given by Mr. Schermerhorn.

No subsequent observations were made at Sault Ste. Marie.

St. Clair River.—St. Clair, 12 miles below Lake Huron. Mean level of Lake Huron, 2.82 feet below high water of 1838.

1867—(See Rpt. Chf. Engr., 1868, p. 949 *et seq.*)—Method of observation, by double floats.

From June 20 to July 19, inclusive, observations were made on 20 days, and all reduced as a single measurement.

Level of Lakes Huron and Michigan, 2.62 feet.

Discharge per second, 233,726 cubic feet.

1868—(See Chf. Engr., 1869, p. 562 *et seq.*)—Observations by meter.

From June 27 to September 17 observations were made on 44 days, only seven of which exceeded one-third the divisions in the cross-section. Reduced as one measurement, the result is as follows:

Level of Lakes Huron and Michigan, 3.42.

Discharge per second, 216,435 cubic feet.

1869—(See Chf. Engrs., 1870, p. 554 *et seq.*)—Observations by meter.

From July 16 to September 3, observations were made on 26 days usually over but one or two divisions of the cross-section. The mean for the series is as follows:

Level of Lakes Huron and Michigan, 2.82.

Discharge per second, 217,658 cubic feet.

The quantities have been compiled in the following groups:

Date.	No.	Local gauge.	Level of lake.	Discharges.	Remarks.
1867.					
June 20–30	8	2.08	2.73	232,732	By double floats.
July 1–11	6	2.05	2.64	234,500	
July 13–19	6	1.99	2.50	236,572	
1868.					
June 27–July 10	9	1.97	3.18	218,118	By meter.
July 16–28	9	1.96	3.22	221,135	
July 29–Aug. 13	9	2.03	3.36	216,088	
Aug. 14–26	8	2.11	3.57	215,791	
Sept. 1–17	9	2.19	3.70	210,226	
1869.					
July 16–27	9	1.02	2.92	205,986	By meter.
July 29–Aug. 20	9	0.94	2.77	220,665	
Aug. 23–Sept. 30	8	0.93	2.80	227,420	

From an inspection of the table it is apparent that it will not be judicious to compare the observations of different years. It is also apparent that the local gauge is not the same in different years.

With these cautions, a careful platting of discharge to gauge does not reveal definite conclusions. Several trends are suggested which apparently indicate results all the way from 16,000 to 50,000 cubic feet for a change of one foot in the level of Lake Huron. In the same manner a variation of 40,000 to 50,000 cubic feet is indicated for a change of one foot in the level of the St. Clair River. It is also apparent that the fluctuation in the river is less than in the lake.

The inference is similar to that derived from the hydraulic conditions. A platting of the quantities in detail does not change the indications.

The discharge at mean lake level is sufficiently indicated by the quantity given by Mr. Schermerhorn, viz., 225,000 cubic feet.

Niagara River.—Below Falls, in the vicinity of Lewiston; mean level of Lake Erie, 2.15 feet below high water of 1838.

1867—(See Rept. Chf. Engrs., 1868, p. 949 *et seq.*) Method of observation, by double floats.

From August 20 to September 25, inclusive, observations were made on 24 days, and all reduced as a single observation:

Level of Lake Erie at Buffalo, 2.36.

Discharge per second, 242,894 cubic feet.

Compiled in groups of six each, the results are as follows:

Date.	Buffalo gauge.	Discharge.	Remarks.
Aug. 20–27	2.18	252,451	Level at Lewiston simply indicates level of Lake. Ontario.
Sept. 2–11	2.30	250,542	
Sept. 12–18	2.42	242,538	
Sept. 19–25	2.54	232,307	

This table indicates a volume of 75,000 cubic feet for a change of one foot on the Buffalo Gauge or in the level of Lake Erie.

1868—(Chf. Engrs., 1869, p. 562 *et seq.*). Observations by meter.

From June 10–September 17 observations were made on sixty-five days, six of which covered half the stream. The data are reduced as two observations and as a whole, as follows:

	Buffalo gauge.	Discharge.
June 10–July 17	1.72	304,307
July 17–September 17	2.20	258,586
June 10—September 17	2.02	273,329

These quantities give 95,000 ft. for a change of one foot in level of Lake Erie.

The following detail table has been compiled from the daily discharges:

Date.	No.	Buffalo gauge.	Discharge.
June 12–30	11	1.68	293,563
July 1–17	14	1.76	290,506
July 22–August 15	15	2.03	258,052
Aug. 18–31	11	2.28	240,800
Sept. 1–17	14	2.34	239,700

This table indicates 87,500 cubic feet as the variation for one foot change of level.

The observations of this and the preceding year are in substantial accord, and indicates a much larger variation of discharge with gauge than that inferred from the hydraulic conditions.

1869—(Chf. Engrs., 1870, p. 554 *et seq.*) Observations by meter.

From June 12–September 25 observations were made on fifty-seven days, of which eleven cover half the stream. The data are reduced as a single measurement:

Level of Lake Erie at Buffalo	1.75
Discharge per second	214,895 cubic feet

From the table of daily discharges the following is compiled:

Date.	No.	Buf. G.	Discharge.
June 10–24	10	1.97	219,810
June 25–July 9	10	1.68	214,438
July 10–27	10	1.48	217,987
July 28–Aug. 13	10	1.49	220,890
Aug. 14–27	10	1.90	192,012
Aug. 28–Sept. 25	7	2.06	212,354

No results are signified.

The volumes for this year are not in accord with those of the two preceding years. These indicate a discharge for mean lake about 5,000 less than heretofore adopted, or 260,000 in lieu of 265,000. It may stand at the latter figures until more conclusively determined.

St. Lawrence River.—At Ogdensburg, 40 miles below Lake Ontario. Mean level of Lake Ontario, 2.39 feet below the high water of 1838.

1867—(Rep. Chf. Engs., 1368, p. 949 *et seq.*)

Method of observation, by double floats.

From August 3 to September 17, observations were made on 19 days, and all reduced as a single measurement.

Level of Lake Ontario at Oswego, 1.45.

Discharge per second, 319,943 cubic feet.

Compiled in groups the results are as follows:

Date.	No.	Odgs. gauge.	Lake Ontario.	Discharge.
August 3–17	7	0.84	1.20	337,539
August 21—September 5	6	1.21	1.45	319,943
September 6–17	6	1.62	1.75	302,346

These quantities give 45,000 cubic feet for a change of one foot at Ogdensburg and 63,000 for a change of one foot in the level of Lake Ontario. The result is similar to that inferred from the hydraulic conditions.

None of the observations cover over one-half the cross-section.

1868—(Chf. Engrs., 1868, p. 562 *et seq.*) Observations by meter.

From June 15 to September 14, observations were made on 53 days, six of which covered one-half or more of the cross-section. The data are reduced as a single observation.

Level of Lake Ontario, 2.60.

Discharge per second, 272,095 cubic feet.

From the daily discharges, the following table is compiled :

Date.	No.	Ogdensburg gauge.	Oswego gauge.	Discharge.
June 15–30	10	1.94	2.32	268,660
July 1–15	11	2.00	2.37	268,262
July 20–31	10	2.27	2.50	270,790
August 3–14	7	2.29	2.60	275,204
August 18–31	8	2.49	2.75	265,220
September 3–14	7	2.60	2.85	267,880

These observations do not indicate any result, except that the fluuctuations are greater at Ogdensburg than at Oswego.

The observations of 1867 indicate 261,000 for the discharge of Lake Ontario at mean level, while those of 1868 indicate 284,000. The latter seems justified by the relative areas of the several basins.

No measurements were made in 1869.

GENERAL CONSIDERATIONS.

The chart of fluctuations for the past 28 years shows that both Lakes Erie and Ontario reach high water before Lakes Huron and Michigan. The high water of Lake Superior sometimes appear to prolong the high water in Huron and Michigan, or brings the culmination later than its normal time. The surfaces of Lakes Erie and Ontario are about 25 per cent. of their total basins and their tributaries are in nearly the same latitude, and also in the storm route, so that they get a concentrated inflow from melting snow or general precipitation. This gives a sharper annual fluctuation and a greater range than for the upper lakes, independent of outlet conditions. These effects may be imposed upon relatively large or small volumes from above, though this variation is limited by the capacity of the outlets and the reservoir action of the upper lakes.

Lakes Michigan and Huron, and Lake Superior also, are each about 40 per cent. of the total areas of their basins, and their tributaries are distributed over a considerable range of latitude, which gives a more gradual supply of snow-water. Both causes would diminish their fluctuations. The precipitation in the Superior basin is also less.

The hydraulic conditions at the several outlets are not the same, and if the lakes were subject to similar conditions in all other respects, the mean annual range, the mean discharge and the increment should have definite relations to each other. The relative value of the several increments should be indicated by the mean discharge divided by the mean range. Assuming 20,000 for the increment of flow due to one foot on Lake Superior, the St. Clair and Niagara rivers would each give 55,000, and the St. Lawrence 47,000. The conditions are not so radically dissimilar as to make this valueless as a general confirmation of previous inferences.

The writer has suggested a regulating dam at the Sault Ste. Marie, not for the purpose of meeting the effects of the abstraction of 10,000 cubic feet at the head of Lake Michigan, but to enable a far larger amount to be taken out for the purpose of improving the navigation of the Mississippi River by additions to its low-water volume, without impairing the level of the several lakes for navigation.

The present discussion makes it apparent that there are large variations in the discharge of the several outlets with variation in stage; the periods of high water are not identical, but those of low water are very nearly so. Any regulation should contemplate no lowering of the low-water plane; in fact, on the contrary, an improvement in steadiness near low water should be maintained.

In order to discuss this matter with a view to positive conclusions, the variation of discharge with gauge height at the several outlets should be carefully ascertained. The records of gauge height for the past thirty years will then enable the variation in discharge to be platted for that period. It is then simply a question of how far the discharge of Lake Superior may be applied so as to equalize the fluctuations on Huron and Michigan, and incidentally of Erie and Ontario. The chart of gauge heights for all the lakes under the new conditions could then be platted.

It is believed that by such regulation the surfaces of all the lakes below Superior could be permanently maintained at considerably over one foot above low water. If so, it would certainly be possible to abstract all the flow due to a variation of one foot without impairing navigation as existing under present conditions.

The effect upon Lake Superior would be to increase its range somewhat. The character of the shores and of the harbors upon this lake are such that no material interests would be seriously affected. The situation at the Sault is such that the cost of such regulation would be comparatively small, probably within one million dollars. The measure should raise no international question, for it would certainly be beneficial to all riparian owners on the other lakes.

There are many most interesting phenomena alluded to by Mr. Henry. The writer has made systematic observations for currents in the open lake, not only near shore, but across the lake from Chicago in 250 feet of water, and has never failed to find them, usually of less than one-half mile per hour. Periodic oscillations in 20-minute intervals are nearly always discernible on the automatic gauge and sometimes they assume a large amplitude, a range of two or three feet. There are many authenticated instances of very large fluctuations without adequate apparent cause.

Seven gauges set about Lake Michigan in 1886 and read at five-minute intervals seemed to show that the periodic oscillations were simply a swing of the water from shore to shore. What is more remarkable, one day's observations showed a general lowering over the whole of Lake Michigan of several inches, which could only have occurred by the transfer of the water to Lake Huron, through the Straits of Mackinaw. These were found to be of the requisite capacity, and the heavy currents found there at times are thus explained. A high barometer on Lake Michigan as compared to Lake Huron, sufficiently accounts for the phenomena. Generally, all these phenomena are referable to meteorological conditions.

The physics of the lakes have never been adequately studied, and it is a profoundedly interesting field for research. The writer had charge, under the Chicago Drainage Commission, of an extended series of observations of great value, but the work was never completed and the results digested. The matter is alluded to for the purpose of stimulating labor in an unworked field.